Agent-Based Modeling of Complex Infrastructures

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Extended Abstract

Complex Adaptive Systems (CAS) can be applied to investigate complex infrastructures and infrastructure interdependencies. The CAS model agents within the Spot Market Agent Research Tool (SMART) and Flexible Agent Simulation Toolkit (FAST) allow investigation of the electric power infrastructure, the natural gas infrastructure and the interdependencies. Several models are currently in use as follows:

- SMART Version 2.0 (SMART II) includes an integrated set of agents and interconnections representing the electric power marketing and transmission infrastructure.
- SMART II VR is a virtual reality interface to SMART II.
- SMART II+ is an extension to SMART II that includes an integrated set of agents and interconnections representing the electric power marketing and transmission infrastructure, the natural gas marketing and distribution infrastructure and the interconnections between the two infrastructures in the form of natural gas fired electric generators.
- FAST is an extension to SMART II that includes improvements in the modeling environment, model detail and representational fidelity.

SMART II

SMART II uses a set of agents and interconnections to represent electric power systems. Two different kinds of agents are included. Generators produce electric power. Consumers use electric power. Interconnections represent the transmission grid.

SMART II considers important economic issues such as investment capital, demand growth for successful consumers, new generation capacity for profitable producers and bankruptcy for noncompetitive organizations.

SMART II VR

SMART II VR is a CAVElib-based virtual reality (VR) interface for SMART II. CAVElib is a virtual reality library developed by the University of Illinois at Chicago.

Generators are shown as green spheres or cubes. Size represents total normalized investment capital levels and can be interactively changed with the CAVE wand. Color represents hourly profit levels.

Consumers are shown as blue spheres or cubes. Size represents total normalized investment capital levels and can be interactively changed with the CAVE wand. Color represents hourly profit levels.

Interconnections are displayed as red tubes. Size represents normalized transmission capacity levels and can be interactively changed with the CAVE wand. Color represents hourly utilization levels.

SMART II VR includes an interactive multifunction wand and two rendering modes.

SMART II+

SMART II+ includes the electric power marketing and transmission infrastructure, the natural gas marketing and distribution infrastructure and the interconnections between the two infrastructures in the form of natural gas fired electric generators. SMART II+ infrastructures include many features:

- Two different kinds of agents, producers and consumers, represent the market participants.
- Interconnections represent transmission or distribution systems with capacities on each line or pipe and complex routing.
- Important economic issues are considered such as investment capital, demand growth for successful consumers, new generation capacity for profitable producers, and bankruptcy for noncompetitive organizations.
- Components can be disabled in real time to simulate failures.

The electric power infrastructure includes the added feature of natural gas fired electric generators. These generators buy fuel from the natural gas market. The resulting electricity is then sold in the electric power market.

The emergent behavior of SMART II+ agents allows investigation of the interdependencies between the electric power and natural gas markets. SMART II+ emergent behavior indicates:

- Natural gas fired electrical generators are highly competitive, which causes their market share to rapidly rise.
- Rising natural gas fired electrical generator market share radically increases market interdependence.
- Increasing market interdependence pits the electric power and natural gas markets against one another during simultaneous failures since both markets are fighting for the same underlying resource, natural gas.

Natural gas market share is rapidly rising in the current market place. This fact leads to the conclusion that emergency natural gas purchases by electrical generators need to be carefully monitored to prevent electrical failures from spreading to the natural gas infrastructure.

FAST

FAST builds on the Spot Market Agent Research Tool Version 2.0 (SMART II). FAST includes many of the features of SMART II along with improvements in modeling infrastructure, detail and fidelity.

Presently FAST has three components as follows:

- FAST:Run is the runtime infrastructure.
- FAST:E is the electric power system model.
- FAST:G is the natural gas system model.

FAST:Run is designed to be a lightweight large-scale system with the following major features:

1. FAST:Run is written entirely in Java.
2. FAST:Run has a fully distributed computation engine.
3. FAST:Run has fully distributed object persistence.
4. FAST:Run has a multithreaded scheduler that focuses on maximizing parallel execution.

FAST:E and FAST:G are built on top of FAST:Run. There are currently plans to merge FAST:Run into the University of Chicago Social Science Research Computing REcursive Porous Agent Simulation Toolkit (RePast). Only a small amount of work will be required to port FAST:E and FAST:G to RePast since FAST:Run is very lightweight.

The underlying design paradigm of FAST is that of a time continuum ranging from decades to seconds:

- On the scale of decades the focus is long term human decisions constrained by economics.
- On the scale of years the focus is short-term human economic decisions constrained by economics.
- On the scale of months and days the focus is short-term human economic decisions constrained by economics and physical laws.
- On the scale of hours the focus is short-term human economic decisions constrained by physical laws and economics.
- On the scale of minutes or less the focus is on physical laws that govern distribution systems.

Over longer time scales human economic decisions are emphasized. Over shorter time scales physical laws dominate. FAST includes a large number of different agents to model these varying time scales. Modeling over the full range of time scales is necessary to understand the complex infrastructure interdependencies between the electric power and natural gas markets.